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THERMAL CONTROL WORKING GROUP REPORT

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The Thermal Control Working Group limited its evaluation to issues associated with earth orbiting and planetary spacecraft with power levels up to 50 kW (Fig. 2). Other missions were judged to be receiving sufficient emphasis (e.g., Space Station, weapon platforms) or were too unique from a thermal design standpoint (e.g., solar probes) for consideration of generic technology needs.

A spacecraft ultimately must reject, as waste heat, all on-board electrical power. The importance of thermal control in spacecraft design has, therefore, increased dramatically in the last few years commensurate with growth in power levels. NASA, Air Force, DOE and SDIO all have numerous thermal technology programs underway (Fig. 3). The working group reviewed these on-going programs against the postulated Spacecraft 2000 missions and design challenges (Fig. 4) to identify new system requirements.

The Group's conclusion was that new technology was necessary to cope with future high watt density electronics, high temperature heat transport and rejection, long term storage of cryogenics and the emerging need to harden all military spacecraft against a wide variety of threats (Fig. 5).

An integrated thermal system for any particular Spacecraft 2000 application will be comprised of many different elements; a list of some of the options the thermal designer has at his disposal are shown on Fig. 6. The number of elements involved prompted a discussion of the value of standardization to increase reliability and lower costs (Fig. 7). The group's consensus was that large weight penalties can result if thermal systems are not uniquely matched to the spacecraft. Hardware standardization in the near term was, therefore, not judged to be cost effective since launch costs dominate. As low cost-to-orbit heavy lift launch vehicles become available this conclusion would change. The one hardware area where standardization would have immediate benefits is in interface designs (e.g., fluid disconnects) to allow orbital replaceable units (ORU's) to be provided by various suppliers (including foreign participants in international programs). Another area of standardization that should be pursued under the S/C 2000 initiative is specifications and test methods for the qualification of new system elements.

The Working Group also concluded that particular emphasis should be placed on the application of robotics to the on-orbit assembly, reconfiguration and maintenance of S/C 2000 thermal systems (Fig. 8).

The primary output of the working group discussions was the definition of high payoff thermal technologies required to meet the objectives of S/C 2000 (Fig. 9). These nine (9) initiatives form the long range technology development plan recommended for implementation. Each of these key thermal system design drivers was assessed by first identifying the problem, the development objective, the approach to achieve possible solutions and any special facilities and equipment that would be needed to meet the development objectives. These nine individual technology plans are presented in Figs. 10 to 18.

These nine key technologies were deemed essential and also met the constraint of appearing feasible within the S/C 2000 time frame. An additional high payoff "wish list" was also prepared to challenge the "inventors" in the thermal community.

As stated earlier, the majority of the group's deliberations were directed at spacecraft type power levels (< 50 kW). Weapon platforms, nuclear propelled manned planetary missions, etc., could require much higher power levels (megawatts). The heat rejection radiator dominates the design of these systems, so development implications (Fig. 20) are to seek very innovative lightweight radiator concepts, efficient heat exchangers to minimize system temperature drops and high temperature (liquid metal) systems to maximize rejection temperature.

In conclusion (Fig. 21), the group determined that the unique new heat pipe radiator and two-phase heat transport systems being developed for Space Station are necessary precursors, but do not meet different S/C 2000 requirements including long life without manned maintenance capability, high watt density electronics, long term cryogenic storage for sensors and/or propulsion/power and threat survivability for military spacecraft. The S/C 2000 initiative should, therefore, include the necessary basic/applied research and ground/space testing to achieve the essential nine (9) new technologies.

Recommended implementation steps (Fig. 22) include the establishment of a steering committee to coordinate the diverse government and industry thermal system development programs to exchange information and avoid overlap. The most pressing need is in-orbit research and development since two-phase thermal systems are inherently not completely ground testable. A space program analogous to the very successful X aircraft series is clearly called for. Of lesser importance, but worth mentioning, are recommendations that the government reexamine

the roles of Universities, National Labs and Industry to confirm that their different expertise is being used to the best advantage. There was some concern expressed by the group that there has been a gradual blurring of roles with all segments of the U.S. technical community competing for the same work with resultant duplication and waste of resources. Finally, there was a similar observation that there may be redundancy in test facilities. It was suggested that an up-to-date handbook of government, university and industry thermal test facilities be prepared. One objective would be to determine if selected national test facilities are desirable (analogous to the national wind tunnels operated by NASA and the Air Force for aircraft development).

It was recognized that the programmatics of X series spacecraft and national test beds is a difficult problem (e.g., cost sharing, protecting proprietary rights, etc.) but the approach has been successfully applied to aircraft development for many years.

PRESENTATION OUTLINE

- o WORKING GROUP ASSUMPTIONS
- o CURRENT THERMAL CONTROL DEVELOPMENT EFFORTS
- o S/C 2000 MISSIONS/DESIGN CHALLENGES
- o NEW THERMAL SYSTEMS REQUIRED FOR S/C 2000
- o THERMAL SYSTEM MAJOR ELEMENTS
- o PROS/CONS OF STANDARDIZATION
- o APPLICATION OF ROBOTICS
- o KEY DRIVERS/HIGH PAYOFF TECHNOLOGIES
- o WISH LIST (UNOBTAINIUMS?)
- o IMPLICATIONS OF HIGHER POWER LEVELS
- o CONCLUSIONS
- o IMPLEMENTATION POLICY

Figure 1.

WORKING GROUP ASSUMPTIONS

- o WILL CONSIDER
 - SCIENTIFIC, COMMERCIAL & MILITARY SPACECRAFT
 - SURVIVABILITY TO NATURAL & MILITARY THREATS
 - OTV'S; CHEMICAL & ELECTRIC PROPULSION, EXPENDABLE & REUSEABLE
 - ON ORBIT DEPLOYMENT/ASSEMBLY, MAINTENANCE
 - POWER LEVELS UP TO 50 KW
- o WILL NOT CONSIDER
 - WEAPON PLATFORMS
 - MANNED SPACECRAFT
 - LAUNCH VEHICLES
 - NEAR SOLAR PROBES

Figure 2.

CURRENT THERMAL CONTROL DEVELOPMENT EFFORTS

- o NASA
 - LeRC - SPACE STATION T/M, $2\phi\mu g$, HIT COMPOSITES, HEAT PIPES, LDR ...
 - JSC - STS T/C, THERMAL TESTBED, THERMAL VAC, ENV. TESTING ...
 - JPL - SP-100, RTG T/M ...
 - GSPC - SCIENTIFIC INSTRUMENT, OPTICS, PRECISION T/C, CPL ...
 - LARC - STRUCTURE T/C, DCHX, H.P. LEADING EDGE ...
 - MSFC - REFRIGERATORS, TES, O-G T/C MAINTAINENCE ...
- o AIRFORCE
 - AFWAL - T/C MATERIALS, TRANSPORT, RADIATORS, TES, COOLERS, SURVIVABILITY ...
 - AFRPL - ADV. MW RADIATORS (LDR, MBR), CRYOSTORAGE, DCHX ...
 - AFOSR - BASIC RESEARCH CAPILLARY, DROPLET H/X MECHANISMS ...
- o DOE
 - "MMW" - CURIE POINT, MEMBRANE RADIATOR, EFD HEAT PIPES ...
 - LANL - LIQUID METAL HEAT PIPE, EM PUMPS, LIFE
 - ORNL, ANL - HIT MATERIALS, TES ...
- o SDIO - TBD

Figure 3.

S/C 2000 MISSION AREAS & DESIGN CHALLENGES

- o MISSION AREAS
 - LWIR, OPTICAL EARTH RESOURCES ...
 - COMMUNICATION PLATFORMS ...
 - SPACE MANUFACTURING ...
 - OTV ...
 - RADAR ATC ...
- o DESIGN CHALLENGES
 - 10 - 30 YEAR DESIGN LIFE ...
 - LEO ASSEMBLY, LEO/GEO TRANSFER ...
 - RESUPPLY, MAINTAINENCE ...
 - INCREASED P/L MASS FRACTION ...
 - GROWTH, MODULARITY, STANDARDIZATION ... AFFORDABILITY ...
 - INCREASED IN-SPACE DATA PROCESSING ...
 - COMPACT, LOCALLY SHIELDED ELECTRONICS ...
 - INTEGRABILITY, TESTABILITY ...

Figure 4.

NEW THERMAL SYSTEMS REQUIRED FOR S/C 2000

- o VERY HIGH HEAT FLUX REMOVAL FORM DENSE ELECTRONICS ("CRAY IN SPACE")
- o NEW HIGH TEMP COOLING SYSTEMS
 - NaS AND LITHIUM BATTERIES (350 - 500°C)
 - HIGH TEMP SOLID STATE ELECTRONICS (150 - 250°C)
- o HIGH TEMP RADIATORS & THERMAL STORAGE FOR ADVANCED POWER SYSTEMS
 - DIPS
 - NUCLEAR
 - ADVANCED SOLAR DYNAMIC
- o LONG TEMP CRYO STORAGE (REFRIGERATORS/RADIATORS)
- o LASER, NUCLEAR RADIATION ETC RESISTENT MATERIALS FOR THREAT SURVIVABILITY

Figure 5.

THERMAL SYSTEM MAJOR ELEMENTS

| | |
|---|------------------------------------|
| COATINGS | DISCONNECTS |
| INSULATION/THERMAL ISOLATORS | FLEX COUPLINGS |
| HEATERS/CONTROLLERS | LOUVERS/SHADE'S |
| RADIATORS (FLUID LOOP & HEAT PIPE) | HEAT PIPES |
| HEAT TRANSPORT LOOPS (SINGLE & TWO PHASE) | STORED CRYOGENS |
| THERMAL STORAGE | MECHANISMS FOR DEPLOYMENT/ASSEMBLY |
| ROTATING JOINTS | PLUME SHIELDS |
| HEAT EXCHANGERS | THERMOELECTRIC COOLERS |
| HEAT PUMPS | CONTACT INTERFACE MATERIALS |
| REFRIGERATORS | THERMAL SWITCHES/DIODES |

Figure 6.

PROS/CONS OF STANDARDIZATION

- o STANDARDIZATION COULD SAVE HARDWARE COST BUT PENALIZES MASS/VOLUME
 - o LAUNCH COST IS CURRENTLY MAJOR COST ELEMENT
- CONCLUSION: HARDWARE STANDARDIZATION IN NEAR TERM NOT COST EFFECTIVE
- o STANDARDIZATION OF SPECS, TEST METHODS ETC.COULD PROVIDE COST BENEFITS
 - o STANDARDIZATION OF INTERFACES IS NECESSARY FOR ORU'S

Figure 7.

APPLICATION OF ROBOTICS

- o MAKE FLUID CONNECTIONS
- o BOLT ELECTRONICS TO COLD PLATES
- o ASSEMBLE RADIATORS
- o REPAIR LEAKS
- o REMOVE & REPLACE COMPONENTS (PUMPS, VALVES ETC.)
- o REPLACE FAILED INSTRUMENTATION
- o REPLENISH FLUIDS
- o CLEAN CONTAMINATED THERMAL COATINGS, OPTICS ETC.

Figure 8.

KEY DRIVERS/HIGH PAYOFF TECHNOLOGIES

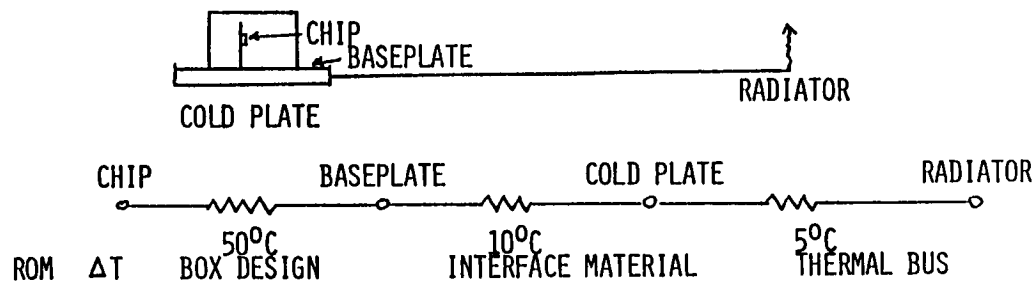
- o BOX LEVEL THERMAL CONTROL
- o HIGH TEMP COOLING LOOPS/ RADIATORS (150 - 500°C)
- o RADIATORS/THERMAL STORAGE FOR ADVANCED POWER SYSTEMS (TO 700°C)
- o LONG TERM CRYO STORAGE
- o THREAT HARDENED MATERIALS
- o BASIC/APPLIED RESEARCH ON LONG LIFE FLUIDS/MATERIALS COMPATIBILITY
- o SCALING/SIMULATION
- o TWO PHASE HEAT TRANSFER MODELLING
- o LONG LIFE ROTATING FLUID GIMBAL

Figure 9.

KEY DRIVER: BOX LEVEL THERMAL CONTROL

PROBLEM

- o S/C LEVEL THERMAL CONTROL SYSTEM. BASIC OBJECTIVE IS TO MAINTAIN COMPONENT (SWITCH, DIODE) ALLOWABLE TEMPERATURE.
- o RADIATOR SIZED RECOGNIZING COMPONENT TO RADIATOR ΔT



OBJECTIVE

- o REDUCE RADIATOR SIZE (COST, WEIGHT, DRAG), NOW DRIVEN BY HIGH ΔT 'S AT BOARD AND BASEPLATE. POTENTIAL FOR 50% RADIATOR SIZE REDUCTION.

APPROACH

- o INSTITUTE COMPONENT THERMAL DESIGN EFFORT
 - UTILIZE BOARD MINI-HEAT PIPES (OR BOARD INTEGRAL WICKS)
 - IMPROVE BASEPLATE/COLD PLATE INTERFACE CONDUCTANCE OR ELIMINATE USING INTEGRAL DISCONNECTABLE FLUID PATH.

SPECIAL FACILITIES AND EQUIPMENT

NONE

Figure 10.

KEY DRIVER: HIGH TEMPERATURE COOLING LOOPS/RADIATORS

PROBLEM

- o EXTEND HEAT PIPE TECHNOLOGY TO NEW HIGHER OPERATING TEMPERATURE AND APPLICATION REGIMES

OBJECTIVE

- o DEVELOP THE TECHNOLOGY BASE FOR THERMAL CONTROL OF HIGH TEMPERATURE POWER ELECTRONICS (150°C - 200°C) AND ADVANCED NaS AND Li BATTERIES (350 - 500°C), SOLARDYNAMIC AND REACTOR P/S SPIN OFF APPLICABILITY ...

APPROACH

- o MATERIAL SELECTION - CLADS, WORKING FLUIDS, PROCESSING TECHNIQUES, MATERIALS COMPATIBILITY, LIFE TEST DATA BASE ...
- o TRANSPORT DESIGN - LOAD INTERFACE HEAT EXCHANGE DESIGN (OPERATING T, HEAT FLUXES, ΔT) ...
 - HEAT TRANSPORT (LOAD TO RADIATOR) ...
 - RADIATOR - VCHP DEV, HP/FIN THERMO-MECHANICAL INTERFACE ...
 - UTILIZE POTASSIUM, MERCURY, CESIUM/TITANIUM OR COMPOSITE HEAT PIPE OR E/M PUMP ASSISTED NaK HEAT PIPE ...
 - COMPOSITE RADIATOR FIN (HIGH k/e)

SPECIAL FACILITIES EQUIPMENT

- LIQUID METAL HANDLING, PROCESSING EQUIPMENT...
- HI VAC LIFE TEST FACILITIES ...
- PRE/POST TEST COMPATIBILITY DIAGNOSTICS ...METALLURGICAL

Figure 11.

KEY DRIVER: RADIATOR/THERMAL STORAGE FOR ADVANCED POWER SYSTEMS

PROBLEM

- o HIGH POWER MISSIONS EXCEED NEAR-TERM RADIATOR CAPABILITY

OBJECTIVE

- o DEVELOPMENT OF ADVANCED, LIGHT WEIGHT RADIATORS AND HIGH TEMPERATURE THERMAL STORAGE DEVICES DESIGNED TO HANDLE HEAT LOADS FROM NUCLEAR/SOLAR POWER SYSTEMS.

APPROACH

- o IDENTIFY HEAT REJECTION REQUIREMENTS FOR SOLAR/NUCLEAR POWER SYSTEMS
- o DEVELOP ENABLING CONCEPTS TO MEET REQUIREMENTS:
 - THERMAL STORAGE INCORPORATING MOLTEN SALT
 - ENCAPSULATED TES
 - COMPOSITE MATERIAL, LIQUID METAL HEAT PIPE RADIATORS
 - HIGH EFFICIENCY HEAT EXCHANGERS
 - REFRACTORY MATERIALS

SPECIAL FACILITIES EQUIPMENT

- o SPACE SIMULATION CHAMBERS WITH HAZARDOUS MATERIALS HANDLING

Figure 12.

KEY DRIVER: LONG TERM CRYOGENIC STORAGE

PROBLEM

- o BOILOFF LOSS IS A SEVERE WEIGHT PENALTY FOR SPACECRAFT

OBJECTIVE

- o DEVELOP LONG TERM CRYOGENIC STORAGE TECHNOLOGY TO STORE HELIUM, HYDROGEN & OXYGEN UP TO 10 YEARS.

APPROACH

- o DEVELOP: HIGH PERFORMANCE INSULATIONS, VAPOR COOLED SHIELD, LOW HEAT LEAK SUPPORTS & PLUMBING, AND CRYO REFRIGERATORS.
- o BUILD & TEST LONG TERM CRYOGENIC STORAGE SYSTEM
- o DEMONSTRATE ON GROUND & ON ORBIT.

SPECIAL FACILITIES

- o HAZARDOUS THERMAL VACUUM FACILITY

NOTE: TECHNOLOGY DEVELOPMENT CURRENTLY UNDERWAY NEEDS CONTINUED SUPPORT
(REQUIRED)

Figure 13.

KEY DRIVER: THREAT HARDENED MATERIALS

PROBLEM

- o THERMAL CONTROL COMPONENT AND SURFACES MAY BE SUBJECTED TO SEVERE HOSTILE ENVIRONMENTS. REQUIREMENTS INCLUDE COATINGS WITH SELECTIVE WAVELENGTH DEPENDENT PROPERTIES, RADIATION INSENSITIVE COATINGS AND FLUIDS, BLAST AND MECHANICAL IMPACT SURVIVABLE COMPONENTS, AND DESIGNS/COMPONENTS TO ACCOMMODATE PULSED LOADS.

OBJECTIVE

- o DEVELOP ADVANCED THERMAL CONTROL MATERIALS, COMPONENTS, CONSTRUCTIONS AND CONFIGURATIONS CAPABLE OF WITHSTANDING PROJECTED THREATS

APPROACH

- o (1) GENERAL DESIGN CONCEPTS FOR DIFFERENT OPERATIONAL REGIMES
- o (2) CONDUCT TRADES
- o (3) SELECT PREFERRED CONCEPTS
- o (4) FABRICATE AND TEST

SPECIAL FACILITIES AND EQUIPMENT

- o OPTICAL PROPERTIES MEASUREMENT, HIGH HEATING, RADIATION, AND HIGH SPEED MECHANICAL IMPACT EQUIPMENT
- o THERMAL VACUUM TEST VERIFICATION

Figure 14.

KEY DRIVER: BASIC/APPLIED RESEARCH IN LONG LIFE FLUIDS/MATERIALS COMPATIBILITY

PROBLEM

- o EXTEND CURRENT HEAT PIPE AND CAPILLARY LOOP COMPATIBILITY DATA BASE TO 10 YEARS (+) FOR 300K - 1000K TEMPERATURE OPERATING REGIME

OBJECTIVE

- o CHARACTERIZE THE LIFE AND PERFORMANCE STABILITY OF ADVANCED TWO PHASE HEAT TRANSFER DEVICES IN 300K-1000K REGIME

APPROACH

- o CHARACTERIZE CORROSION, MASS TRANSPORT, AND PERFORMANCE DEGRADATION MECHANISMS IN ADVANCED 2 PHASE TRANSPORT DEVICES AS FUNCTION OF NORMALIZED MASS FLOW RATES, TEMPERATURE, VAPOR PRESSURE, VACUUM BACKGROUND PRESSURE
- o CHARACTERIZE OPTIMUM PROCESSING, ASSEMBLY, FABRICATION TECHNIQUES TO ENHANCE ATTAINABLE LIFE
- o CONDUCT ACCELERATED AND REAL TIME LIFE TESTS TO VERIFY CORROSION MODEL VALIDITY.

SPECIAL FACILITIES AND EQUIPMENT

- o HIGH VACUUM TEST FACILITIES
- o SURFACE CHEMISTRY, METALLURGICAL DIAGNOSTICS
- o LIQUID METAL HANDLING AND ASSAY EQUIPMENT

Figure 15.

KEY DRIVER: SCALING/SIMULATION

PROBLEM

- o TESTING OF FULL SIZE FLIGHT HARDWARE OFTEN DIFFICULT OR IMPOSSIBLE DUE TO SIZE
- o MICRO - G OPERATION UNVERIFIABLE PRIOR TO FLIGHT

OBJECTIVE

- o PREDICT IN-FLIGHT PERFORMANCE BY MEANS OF GROUND TEST

APPROACH

- o REDUCED SCALE 1-G AND/OR BRIEF MICRO-G TESTING
- o DEVELOP ANALYTICAL TECHNIQUES TO EXTRAPOLATE REDUCED SCALE TEST DATA TO THE FULL SIZE CONFIGURATION AND 1-G (OR BRIEF MICRO G) ENVIRONMENT TO PROTRACTED MICRO-G OPERATION.

SPECIAL FACILITIES AND EQUIPMENT

- o EXISTING

Figure 16.

KEY DRIVER: TWO PHASE HEAT TRANSFER MODELLING

PROBLEM

- o TWO PHASE HEAT TRANSFER ANALYTICAL TOOLS NEEDED TO PREDICT SYSTEM PERFORMANCE

OBJECTIVE

- o DEVELOP SOFTWARE TO PERMIT CONFIDENT PREDICTIONS OF PERFORMANCE

APPROACH

- o CONSTRUCT COMPUTER PROGRAM WITH TRANSIENT AND STEADY STATE CAPABILITY AND GENERAL APPLICABILITY - VARIABLE G, ARBITRARY DIMENSIONS, SELECTED WORKING FLUID AND MATERIALS
- o CORRELATE AGAINST DATA FROM VARIOUS TEST CONFIGURATIONS
- o USE VALIDATED MODEL TO CHARACTERIZE IN-FLIGHT PERFORMANCE

Figure 17.

KEY DRIVER: LONG LIFE ROTATING FLUID GIMBAL

PROBLEM

- o MANY MILITARY & SCIENCE MISSIONS REQUIRE TAKING COOLING LINES ACROSS GIMBALS.
- o SPACE STATION IS DEVELOPING A ROOM TEMPERATURE GIMBAL
- o PERIODIC MAINTENANCE IS PERMITTED

OBJECTIVE

- o DEVELOP LONG LIFE CRYOGENIC AND HIGH TEMP ROTATING FLUID GIMBALS

APPROACH

- o PHASED PROGRAM
 - LONG LIFE SEAL TESTS
 - GIMBAL DESIGN AND PROTOTYPE FAB. (CRYO & HIGH TEMP)
 - LIFE TESTS

SPECIAL FACILITIES AND EQUIPMENT

- o STD VACUUM CHAMBER

Figure 18.

WISH LIST (UNOBTAINIUMS?)

- o CRYOGENIC THERMO ELECTRICS (HIGH COP AT LARGE ΔT), OR OTHER TYPE OF NO-MOVING-PARTS REFRIGERATOR
- o INTERFACE MATERIAL WITH CONDUCTANCE OF BRAZED JOINTS
- o PHOTOCHROMIC COATINGS THAT CHANGE $\alpha \text{ \& } \epsilon$ WITH TEMPERATURE (PASSIVE LOUVER)
- o HEAT PIPE FLUID FOR APPLICATION BETWEEN WATER AND LIQUID METALS
- o HIGH THERMAL ENERGY STORAGE SYSTEMS
- o EXTREMELY HIGH CONDUCTIVITY HIGH TEMP. RADIATOR FINS (BETTER THAN CARBON/CARBON)

Figure 19.

IMPLICATIONS OF HIGHER POWER LEVELS (MEGAWATTS)

- o RADIATOR IS VERY LARGE (ACRES) AND IS THE DOMINANT MASS.
- o ADVANCED VERY LIGHT CONCEPTS ARE REQUIRED

RADIATORS

- o LIQUID DROPLET & CURIE POINT (MAGNETIC)
- o FREE LIQUID SURFACE ROTATING DISKS
- o MOVING BELTS (DRY OR WET)
- o SPHERICAL MEMBRANE
- o EXPANDABLE (PARTY WHISTLE)

HEAT EXCHANGERS

- o DIRECT CONTACT OF FLUID STREAMS
- o SPRAY FED CAPILLARY WICKED SURFACES
- o SINGLE PHASE JET IMPINGEMENT
- o ENTRAINED MICROENCAPSULATED PHASE CHANGE MATERIAL IN FLUID

LIQUID METAL SYSTEMS

- o EM PUMPS
- o SINGLE & TWO PHASE LOOPS, HEAT PIPE RADIATORS

Figure 20.

CONCLUSIONS

- o SPACE STATION TECHNOLOGY IS NECESSARY PRECURSOR BUT DOES NOT MEET S/C 2000 NEEDS
 - LIFE, HIGH HEAT FLUX, LONG TERM CRYO AND SURVIVABILITY
- o ADDITIONAL BASIC AND APPLIED RESEARCH REQUIRED
 - FLUID/MATERIALS COMPATIBILITY, TWO PHASE SYSTEM MODELLING
- o SCALING IS KEY ISSUE
 - MUST DEFINE ACCELERATED LIFE TEST CRITERIA
 - TWO PHASE SYSTEMS REQUIRE 0 G TO 1 G CORRELATION
 - SYSTEM SIZE MAY PRECLUDE FULL SCALE GROUND TEST
- o ADDITIONAL GROUND TEST BEDS ARE REQUIRED
 - MATERIALS COMPATIBILITY
 - COMPONENT LIFE TESTS (HEAT PIPES, PUMPS, VALVES ETC)
 - SYSTEM LIFE TESTS OF TOTAL HEAT TRANSPORT LOOP
- o COMBINED SPACE ENVIRONMENT TESTS OF MATERIALS

Figure 21.

IMPLEMENTATION POLICY

- o ORGANIZE SMALL SPACECRAFT THERMAL SYSTEM STEERING COMMITTEE
 - MILITARY, NASA AND INDUSTRY PARTICIPANTS
 - YEARLY MEETING TO ASSESS NEED, TRENDS AND RECOMMEND NEW INITIATIVES
- o ESTABLISH AN X-1,2,3 EXPERIMENTAL SPACECRAFT PROGRAM ANALOGOUS TO X SERIES AIRCRAFT
 - GENERALLY LAUNCHED ON ELV'S BUT OCCASSIONALLY COULD USE SHUTTLE FOR RETRIEVAL
E.G. LDEF
- o RE-EXAMINE ROLES / FUNDING OF UNIVERSITIES, NAT LABS, SMALL BUSINESS & AEROSPACE COMPANIES
- o COMPILE A HAND BOOK OF EXISTING AND PLANNED U.S. TEST FACILITIES FOR THERMAL SYSTEM VALIDATION
 - VACUUM CHAMBERS
 - COMBINED ENVIRONMENTS
 - COOLING LOOP TEST BEDS
 - HEAT PIPE LIFE TESTS
 - ETC
- o DETERMINE IF ADDITIONAL NATIONAL MULTI-USE TEST FACILITIES ARE DESIRABLE

Figure 22.